DISTRIBUTION OF BLACK-TAILED JACKRABBIT HABITAT DETERMINED BY GIS IN SOUTHWESTERN IDAHO

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Abstract: We developed a multivariate description of black-tailed jackrabbit (*Lepus californicus*) habitat associations from Geographical Information Systems (GIS) signatures surrounding known jackrabbit locations in the Snake River Birds of Prey National Conservation Area (NCA), in southwestern Idaho. Habitat associations were determined for characteristics within a 1-km radius (approx home range size) of jackrabbits sighted on night spotlight surveys conducted from 1987 through 1995. Predictive habitat variables were number of shrub, agriculture, and hydrography cells, mean and standard deviation of shrub patch size, habitat richness, and a measure of spatial heterogeneity. In winter, jackrabbits used smaller and less variable sizes of shrub patches and areas of higher spatial heterogeneity when compared to summer observations ($P < 0.05$). During the low population phase, jackrabbits also used agricultural regions more during winter than summer. The association with agricultural regions was emphasized spatially in a GIS map contrasting winter and summer periods. Multivariate habitat means ($P < 0.001$), but not individual GIS variables ($P > 0.05$), differed significantly between high and low population phase. We used the Mahalanobis distance statistic to rank all 50-m cells in a 440,000-ha region relative to the multivariate mean habitat vector. On verification surveys to test predicted models, we sighted jackrabbits in areas ranked close to the mean habitat vector. Areas burned by large-scale fires between 1980 and 1992 or in an area repeatedly burned by military training activities had greater Mahalanobis distances from the mean habitat vector than unburned areas and were less likely to contain habitats used by jackrabbits.

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Black-tailed jackrabbits are important prey for raptors and other predators (Clark 1972, Johnson and Hansen 1979, Smith and Murphy 1979, MacCracken and Hansen 1987, Bates and Moretti 1994). In the NCA and surrounding region in southwestern Idaho, black-tailed jackrabbits and other abundant prey support one of the largest nesting densities of raptors in the world (U.S. Dep. Inter. 1979; Steenhof and Kochert 1985, 1988). A holistic approach is necessary for management of ecological systems (Grumbine 1994). Therefore, managers should address nongame prey populations in land use planning to achieve often more visible goals, such as conservation of raptors, in a region.

The NCA, designated as a national conservation area (U.S. Public Law 103-64, 4 Aug 1994), also is used for livestock grazing, and military training. Wildfires are an additional disturbance to the habitat in the NCA and in recent years have fragmented shrublands and changed much of the landscape to exotic annual grasslands (Knick and Rotenberry 1995). In addition to temporal effects, land use and distur-

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bance can influence considerably the spatial distribution of habitats used by wildlife (Dunning et al. 1995, Holt et al. 1995, Turner et al. 1995).

Our first objective was to develop a multivariate description of habitats associated with jackrabbits observed on spotlight counts during winter and early summer of high and low phases in their population (Johnson and Peek 1984). We used the Mahalanobis distance statistic as an index relative to the multivariate mean habitat vector to rank individual cells in a GIS map of the entire study area. We used this technique to determine differences in spatial distribution of habitats associated with jackrabbits by season and population phase. We also examined the effect of large-scale fires on jackrabbit habitat in areas burned by wildfire between 1980 and 1992, or in a 21,715-ha area repeatedly burned by fires ignited during training by the military.

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STUDY AREA

We conducted our study in about 440,000 ha of southwestern Idaho that included portions of the NCA (116°W, 43°N) on both sides of the Snake River Canyon. The region was relatively flat, semiarid rangeland and consisted of mixed shrublands, grasslands, and agriculture. Big sagebrush (*Artemisia tridentata*) communities in the northwest graded into saltshrub communities, including shadscale (*Atriplex confertifolia*) and winterfat (*Krascheninnikovia lanata*) in the south (Yensen and Smith 1984). Numerous fires between 1980 and 1992 converted about one-half of the native shrub communities to areas dominated by cheatgrass (*Bromus tectorum*), Russian thistle (*Salsola kali*), and annual mustards (*Descurainia* spp. and *Sisymbrium* spp.). Of the 76,910 ha that have burned between 1980 and 1992, 52,550 ha have burned once, 20,890 ha have burned twice, and 3,310 ha have burned 3 times. Maximum daily temperature at the Swan Falls weather station, located within the study area, averaged 4.9 C during December-January and was 33.6 C in June-August from 1948 to 1992; annual precipitation averaged 19.9 cm.

Primary land use activities in our study area were irrigated agricultural crops, livestock grazing, and military training (Kochert and Pellant 1986). Livestock (cattle, sheep, and horses) were grazed during variable seasons of use from September through June throughout the study area (U.S. Dep. Inter. 1995).

Areas used for military training were restricted in 1953 from the Snake River Plain and Canyon to the Orchard Training Area (approx 56,000 ha), within the current NCA. Within the Orchard Training Area, artillery and tank gunnery practice are conducted from a perimeter road into a 21,715-ha interior region (the Range Road Interior). Fires ignited during training were allowed to burn within the Range Road Interior until 1988, when a program for immediate suppression was implemented (U.S. Dep. Inter. 1995). Fire boundaries and area burned were not recorded within the Orchard Training Area.

Black-tailed jackrabbits inhabited the entire NCA. Populations of black-tailed jackrabbits in Idaho undergo regular fluctuations in abundance; peaks in population repeat at intervals of 7–12 years (Johnson and Peek 1984). In the NCA, previous periods of high populations were recorded in 1970–71, 1980–82, and 1990–92 (U.S. Dep. Inter. 1979, Johnson and Peek 1984, this study).

METHODS

Black-Tailed Jackrabbit Surveys

We determined locations of jackrabbit home ranges from observations on spotlight line-transect surveys (Smith and Nydegger 1985). Established survey routes were driven 2–3 times during each summer or winter period. We conducted surveys on 2-track dirt roads distributed throughout the study area, and sampled all available habitats, treatments (burned or unburned) and regions within the study area. Total distances sampled during individual survey periods ranged from 394 to 709 km.

We determined locations of survey routes by GPS to an estimated accuracy of ±10–12 m. We

Table 1. Black-tailed jackrabbit surveys in the Snake River Birds of Prey National Conservation Area, southwestern Idaho.

Year	Season	Rabbits obs. (n)	Survey dist. (km)	Density n/ha[a]	CV[a]	Pop. phase
1987	Summer	82	614	0.04	16.4	Low
1988	Summer	187	674	0.07	11.8	Low
1989	Summer	274	709	0.09	8.5	Low
1990	Summer	675	702	0.20	5.9	High
1990–91	Winter	216	394	0.16	8.9	High
1991	Summer	674	604	0.22	6.2	High
1991–92	Winter	454	709	0.09	6.7	High
1992	Summer	963	709	0.24	5.4	High
1992–93	Winter	422	660	0.05	7.8	Low
1993	Summer	203	660	0.06	9.7	Low
1993–94	Winter	151	663	0.06	8.6	Low
1994	Summer	371	660	0.14	7.1	Low
1994–95	Winter	125	660	0.02	11.4	Low

[a] Densities and CV estimated with program DISTANCE (Laake et al. 1993) with the half-normal model.

recorded the location of jackrabbit observations on the survey route from the vehicle odometer (±0.08 km). We then used the road position as the location of the sighting because most sightings (4,818/4,893) were <100 m of the road.

We conducted surveys during early summer (May–Jun) from 1987 through 1994, and winters (Nov–Jan) 1990–91 through 1994–95. We separated summer and winter periods because of potential differences in jackrabbit habitat use and distribution (Grant 1987, Knick 1990, Smith 1990). Our surveys included 3 years of high (1990–92) and 6 years of low populations (1987–89; 1993–95) of jackrabbits (Table 1). We included winter 1992–93 in the low population sample because of similarity in the density estimate to subsequent years (Table 1).

We assumed that our observation represented the general location of a home range rather than an individual's selection of a precise point within the range because of the coarseness in recording sighting locations and the scale of our measures for habitat characteristics. Therefore, we determined habitat associations at the scale of home range selection within the study area (Johnson 1980) and for the jackrabbit population, without identification of individual rabbits (Design 1, Thomas and Taylor 1990).

GIS Methods

We developed a GIS coverage of survey routes by importing the GPS coordinates into a raster-based map (ARC/GRID; Environ. Systems Res. Inst. 1993). We then determined coordinates of jackrabbit sightings from odometer records (ARC/INFO; Dynamic Segmentation; Environ. Systems Res. Inst. 1993). Coordinates were combined with GIS coverages to develop the multivariate set of habitat characteristics describing each sighting. Because we assumed that sightings represented an individual's range, we determined habitat characteristics for a 1-km radius around each sighting, an area (314 ha) about the size of jackrabbit home ranges in northern Utah (<100–300 ha; Smith 1990).

We developed a habitat map for the NCA by classifying Landsat thematic mapper satellite images from 9 September 1990 and 30 March 1991 into 5 habitat classes: sagebrush, shadscale, winterfat, disturbed areas (including Russian thistle), and grasslands (including cheatgrass, Sandberg's bluegrass [*Poa secunda*], and bottlebrush squirreltail [*Elymus elymoides*]; Knick et al. 1997). In addition, we delineated agriculture, canyon, and water areas. We developed GIS layers for shrub/non-shrub pixels in the images as well as individual habitat classes. Shrub cells represented areas with >5% ground cover of shrubs. Accuracy of the classified map, determined from an independent set of ground points of known habitats, was 80% in separating shrub from non-shrub areas and 64% in distinguishing individual habitat classes (Knick et al. 1997).

We created a gridded coverage of the study area by re-sampling the 30-m pixels in the satellite image into 50-m grid cells. Re-sampling also reduced the number of cells in the GIS map by about one-third. Thus, the resolution of the habitat map was 50 m and the study area (438,085 ha) contained 1,752,340 grid cells (compared to 4,867,611 cells at a map resolution of 30-m cells).

We determined large-scale habitat characteristics for the area within a 1-km radius of each 50-m grid cell by moving window functions in the GIS (ARC/GRID; Environ. Systems Res. Inst. 1993). From the classified image, we determined a habitat richness value (no. of different habitats) for each cell. Also from the classified satellite image, we determined 4 habitat variables that described characteristics of shrub patches: number of shrub cells (an estimate of total shrub cover within the individual's home range), average size and standard deviation (a measure of variation in size) of shrub patches, and an index of spatial heterogeneity in the landscape.

We described the spatial heterogeneity, or patchiness (Li and Reynolds 1994), of the shrub mosaic surrounding each location by the proportion of edges between cells having different habitats to total number of edges within the 1-km radius. Each cell in the map had 4 edges. We used only edges between shrub and grassland habitats because of the accuracy in image classification. The patchiness index, P, varied from 0 (all edges were similar) to 1 (all edges were different).

We created a map layer for the number of hydrography cells within a 1-km radius of each cell in the GIS coverage. U.S. Geological Survey 1:100,000 Digital Line Graphs of hydrography features were converted to 50-m cells to conform to the resolution of the habitat map. Hydrography cells included any edge with wetlands, lakes, or ephemeral and permanent streams or rivers. Number of agriculture cells (the max. area, including fallow fields used for agriculture since 1979) was determined from a composite of the 1979 Snake River Birds of Prey vegetation map (U.S. Dep. Inter. 1979), 1993 Bureau of Reclamation agriculture maps, and the vegetation map classified from satellite imagery.

Map layers of areas that burned outside of the Orchard Training Area between 1980 and 1992 were digitized from 1:24,000 quadrangle maps in Bureau of Land Management files. The boundary of the Range Road Interior was digitized from 1:24,000 quadrangle maps.

One fire burned 276 ha in 1994, after the habitat map was classified and included 1.4 km of a survey route. Otherwise, habitats remained similar along survey routes during the study and did not change after the GIS map was classified from 1991 satellite imagery.

Habitat Associations

We corrected for sampling bias between shrub and non-shrub habitats because different probabilities of detection of jackrabbits related to vegetation cover would influence our analysis of habitat associations if we gave equal weight to both habitats (e.g., we might be more likely to see jackrabbits in grasslands because of less vegetation cover even though the populations might be more dispersed). We weighted each observation by the inverse of the detection probability of jackrabbits, determined from the DISTANCE program (Laake et al. 1993) using the half-normal model to fit the data (Buckland et al. 1993). We recorded shrub or non-shrub class at the time of sighting for observations during 1990 through 1994. We tested for differences in the detection probability for spring versus winter within shrub or non-shrub habitats, and between habitats for combined seasons by z-test (Dixon and Massey 1969).

We first tested for general habitat associations for jackrabbit sightings pooled within summer and winter periods during high and low population phase. Habitat characteristics were compared by χ^2 goodness-of-fit tests between samples of sightings and expected values derived from proportions within the study area for individual habitat coverages. Bonferroni confidence intervals were constructed for observed sample proportions to determine individual classes that significantly differed from expected (Manly et al. 1993). We pooled classes when necessary to ensure that the expected value of each cell was ≥ 5 (Sokal and Rohlf 1981).

We tested for differences in the mean vector of habitat characteristics among population phase and seasons by a MANOVA (Seber 1984) with a population phase*season interaction. For significant treatments, we performed subsequent pairwise univariate comparisons using a Bonferroni adjustment to determine variables contributing to significant overall effects in the MANOVA.

Habitat variables were transformed and tested for normal distributions (PROC UNIVARIATE; SAS Stat. Inst. 1990). The probability of deviation from normal distributions remained significant ($P < 0.01$) for all transformed variables. However, the Kolmogorov-Smirnov statistic was small ($D < 0.10$ for each variable (except no. of agriculture cells) and the statistical power was the result of large samples. We tested among log and power transformations and selected the transform that best approached a normal distribution as determined by the Kolmogorov-Smirnov test. Average patch size and standard deviation were transformed by $\log_{10}(x + 0.5)$, hydrography by $x^{0.8}$, number of shrub cells by $x^{0.4}$, patchiness index by $x^{0.9}$, and habitat richness by x^2. Transformations did not improve the distribution of number of agriculture cells and were not used.

Habitat Index Maps

We used the Mahalanobis distance statistic as a measure of similarity to the mean vector of habitat characteristics. The Mahalanobis distance statistic is dimensionless and does not imply an actual probability of occupancy by jackrabbits. However, equal values do imply an equal probability of similarity to the mean (Seber 1984: 10). Although the Mahalanobis distance can be converted to a χ^2 probability (Clark et al. 1993), we used the unscaled metric simply to rank each cell in the habitat map relative to a statistical description of habitats used by jackrabbits.

We created maps of the Mahalanobis distance for each cell in the study area relative to the vector describing the multivariate characteristics of habitats at cells where jackrabbits were sighted. To calculate the Mahalanobis distance, we used continuous values for all habitat variables rather than the categorical values used in the initial χ^2 analysis for general habitat associations. We used the transformed variables in determining the Mahalanobis distance. Although the Mahalanobis distance can be calculated for variables of any distribution, the properties are best known when the assumption of multinormality is correct. Because of unequal probability of sighting in shrub and grass habitats, we determined the Mahalanobis distance to a Horvitz-Thompson weighted mean and variance-covariance matrix.

Model Verification

We tested the predictive ability of our GIS maps of habitat ranks from verification surveys. First, we used multivariate habitat models derived for jackrabbits sighted on surveys during low populations in 1987–89 and 1992–93 to develop the GIS map of Mahalanobis distances. We then used the Mahalanobis distance for the cells in which jackrabbits were sighted on verification surveys conducted in summer 1994 and from winters 1993–94 and 1994–95, again during a low population phase. To insure independence from the calibration set, verification sightings were not included in developing the initial model of habitat associations.

Analysis of GIS Habitat Maps

We determined changes in the relative ranks of habitat cells in the GIS map for season and population phase by comparing the cumulative frequency distribution of the Mahalanobis distances in the study area. Because the GIS variables at each cell did not change, the difference in Mahalanobis distance, or relative ranking, is a function of that cell's relation to the mean habitat vector. A decrease in the Mahalanobis distance would indicate an increase in that cell's similarity to the mean habitat vector. Similarly, area-wide changes indicate a relative contraction or expansion in the number of cells similar to habitats used by jackrabbits during a season or population phase.

We determined the effect of large-scale wildfires on jackrabbit habitat from the cumulative frequency distribution of the Mahalanobis distances for burned and unburned areas since 1980 within the NCA and within the Range Road Interior (repeatedly burned). Difference in distributions indicate relative likelihood of the region to contain habitats associated with jackrabbits.

We assessed the spatial distribution of habitat changes between GIS maps by a cell by cell subtraction of Mahalanobis distances. Cells that did not change between maps should have a value of 0; differences greater than a threshold value indicate a change in relative rank. We defined significant change as >2 SD determined from the distribution of the differences between maps.

RESULTS

Black-Tailed Jackrabbit Surveys

Number of jackrabbits sighted during individual surveys ranged from 82 to 963 (Table 1). Number of pooled observations within season and population phase used to develop the models of habitat association ranged from 422 to 2,322. Number of rabbit sightings used to verify map predictions was 371 for summer and 276 for winter surveys.

Table 2. GIS variables ($\bar{x} \pm$ SE) contributing to significant differences in the mean vector of habitat associations of black-tailed jackrabbits between summer and winter observations. Pairwise comparisons were made with a Bonferroni-adjusted significance level.

GIS variable	Season of year: Summer (n = 3,095) $\bar{x}$	Summer SE	Winter (n = 1,064) $\bar{x}$	Winter SE
No. shrub cells[a]	812.3	5.2	794.6	8.9
Mean patch size (m^2)[b]	5.86×10^7	1.00×10^6	5.76×10^7	1.76×10^6
Patch variability (m^2)[c]	3.24×10^7	4.77×10^5	3.18×10^7	8.51×10^5
Habitat patchiness[d]	489.9	3.8	509.9	6.8

[a] Analysis performed on transformed data; $F = 7.40$, $P = 0.007$.
[b] Analysis performed on transformed data; $F = 8.75$, $P = 0.003$.
[c] Analysis performed on transformed data; $F = 11.20$, $P = 0.001$.
[d] Analysis performed on transformed data; $F = 13.06$, $P = 0.001$.

The detection probability (P_j) of jackrabbits did not differ in comparisons between seasons within shrub ($z = 1.19$, $P = 0.25$) or non-shrub habitats ($z = 1.26$, $P = 0.20$) but was consistently different between habitat groups ($P < 0.001$). Therefore, we combined sightings for all years and weighted each observation in the habitat analyses by the inverse of the detection probability for shrub ($P_j = 0.039$) and non-shrub ($P_j = 0.032$) classes ($z = 3.87$, $P < 0.001$).

Habitat Associations

General patterns of large-scale habitat associations of jackrabbits were similar for season and population phase. The 1-km radius surrounding jackrabbit sightings contained fewer agriculture ($\chi^2 = 1605.9$, 4 df, $P < 0.01$) and more shrub cells ($\chi^2 = 1264.5$, 4 df, $P < 0.01$) than expected. Jackrabbits were seen less frequently than expected in areas with either low or high numbers of hydrography cells ($\chi^2 = 814.3$, 4 df, $P < 0.01$), or in low or highly diverse habitats ($\chi^2 = 2227.1$, 11 df, $P < 0.01$). Areas surrounding jackrabbit sightings were associated with larger patch sizes of shrubs ($\chi^2 = 4143.7$, 3 df, $P < 0.01$), greater variability in patch size ($\chi^2 = 3823.8$, 3 df, $P < 0.01$), and greater spatial heterogeneity ($\chi^2 = 1752.0$, 2 df, $P < 0.01$).

Mean vectors of habitats associated with jackrabbits were significantly different among population phase (Wilks' $\Lambda = 0.992$, $F_{7,4149} = 4.63$, $P < 0.001$), season (Wilks' $\Lambda = 0.984$, $F_{7,4149} = 9.56$, $P < 0.001$), and population phase*season (Wilks' $\Lambda = 0.989$, $F_{7,4149} = 6.71$, $P < 0.001$). No single variable was significantly different ($P > 0.05$) in pairwise univariate comparisons between high and low populations. In seasonal differences, jackrabbits were observed in areas of more shrub cells, larger and more variable shrub patches, but lower landscape patchiness in summer when compared to winter transects (Table 2).

Differences between season of year were accentuated during the low population phase in the analysis of population phase*season interactions (Table 3). In the significant univariate comparisons, winter and spring periods during the low populations represented the extremes compared to the intermediate values observed during both seasons of high populations (Table 3). In addition to using smaller shrub patch sizes and higher landscape patchiness, jackrabbits in winter during the low populations used agricultural regions more in comparison to the other treatments (Table 3).

Model Verification

We sighted jackrabbits on verification surveys during low populations in summer 1994 and

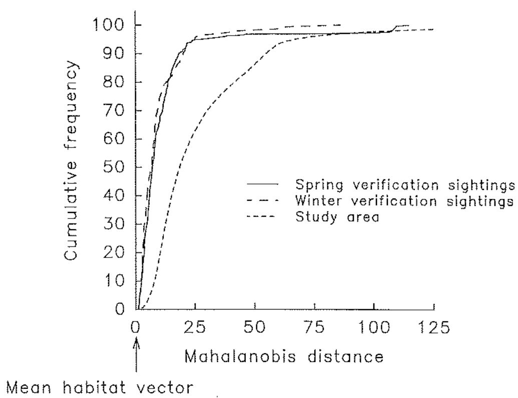

Fig. 1. Cumulative frequency distribution of the Mahalanobis distances for cells in a GIS map where jackrabbits were sighted on verification surveys, and for the study area in southwestern Idaho. The map contained 440,000 ha in southwestern Idaho and included portions of the Snake River Birds of Prey National Conservation Area.

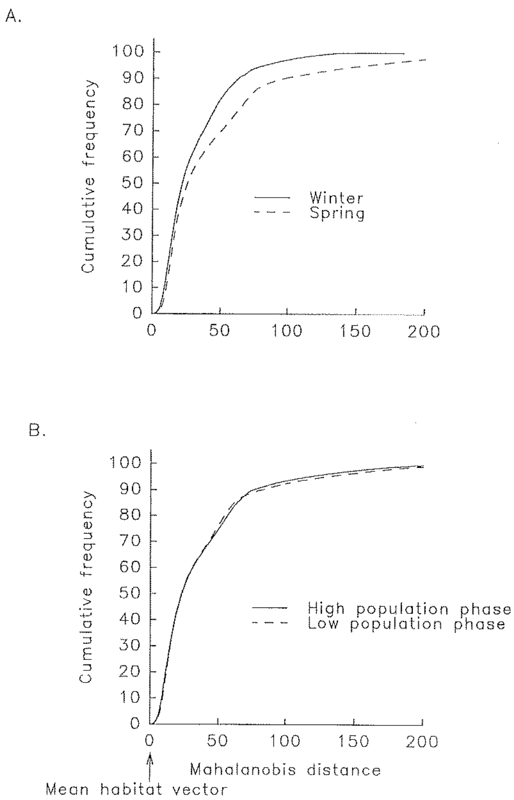

Fig. 2. Cumulative frequency distribution of the Mahalanobis distances for the GIS map created from habitat associations of jackrabbits sighted during different seasons (A) or phases of the population (B). The GIS map contained 440,000 ha in southwestern Idaho and included portions of the Snake River Birds of Prey National Conservation Area.

winters 1993–94 and 1994–95 in habitat cells ranked in the top portions of the GIS maps. We sighted 50% of the jackrabbits in cells classed in the top 7%, and 75% of the jackrabbits in the top 30% of distributions of Mahalanobis distances (Fig. 1).

Analyses of Habitat Maps

The cumulative frequency distribution of Mahalanobis distances was shifted toward greater values (lower similarity) during the summer period when compared to winter (Fig. 2A). Most of the difference was in the largest 60% of the ranks in the distribution (Fig. 2A). In contrast to differences between seasons, the cumulative frequency distribution of Mahalanobis distances was similar between low and high phases of the population and indicated that the amount of habitats remained the same within relative rankings (Fig. 2B).

Table 3. GIS variables ($\bar{x} \pm$ SE) contributing to significant differences in the mean vector of habitat associations of black-tailed jackrabbits among population phase and season of year treatments. Variable means with the same letters are not significantly different ($P < 0.05$). Pairwise comparisons were made with a Bonferroni-adjusted significance level.

GIS variable	Low population				High population			
	Summer (n = 773)		Winter (n = 413)		Summer (n = 2,322)		Winter (n = 651)	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
No. agric. cells[a]	30.7B	2.4	54.6A	7.2	40.8AB	2.5	30.6B	3.8
No. shrub cells[b]	840.4A	10.1	767.3B	14.6	802.9AB	6.0	812.0AB	11.2
Mean patch size (m^2)[c]	6.24×10^7A	2.12×10^6	5.81×10^7B	2.96×10^6	5.73×10^7AB	1.13×10^6	5.73×10^7AB	2.18×10^6
Habitat patchiness[d]	470.5B	7.5	533.0A	11.3	496.4AB	4.5	495.2B	8.4

[a] $F = 16.52$, $P = 0.001$.
[b] Analysis performed on transformed data; $F = 12.36$, $P = 0.001$.
[c] Analysis performed on transformed data; $F = 6.06$, $P = 0.014$.
[d] Analysis performed on transformed data; $F = 14.13$, $P = 0.001$.

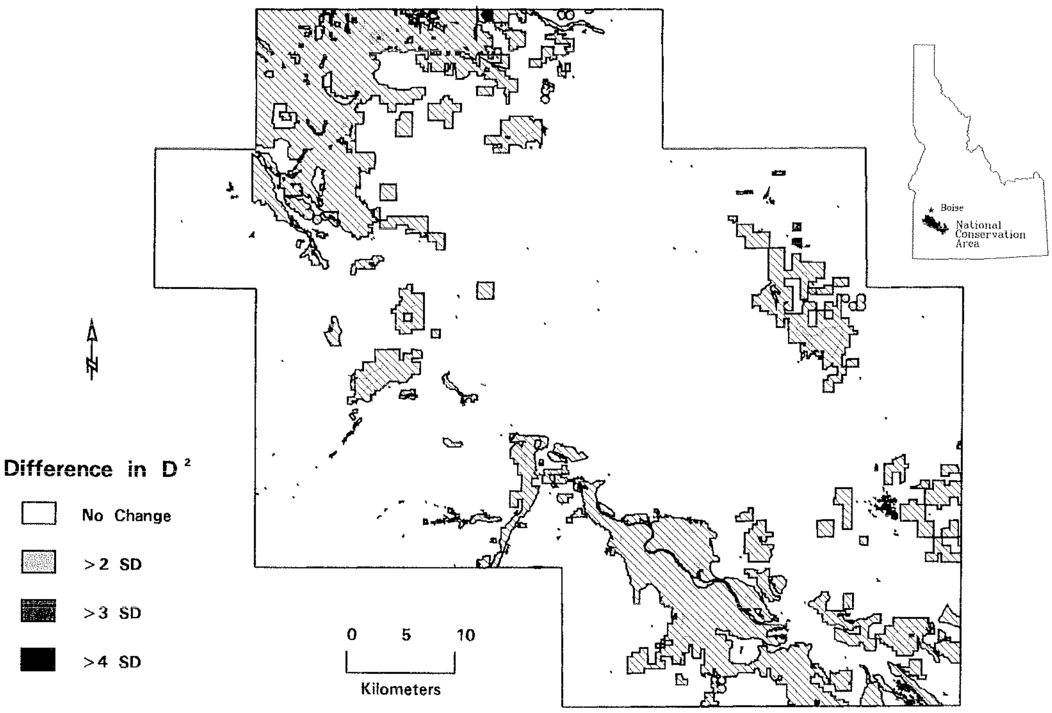

Fig. 3. Change in Mahalanobis distances between summer and winter periods relative to agricultural areas in southwestern Idaho. We defined change as >2 SD of the distribution of the differences between GIS maps.

We compared GIS maps between summer and winter during low populations because of the large contrast in mean habitat vectors (Table 3). The amount of habitat similar to the mean habitat vector (no. cells with smaller Mahalanobis distances) in winter was expanded relative to the summer period (Fig. 3). In addition, areas with changes in the Mahalanobis distances >2 SD illustrated the increased association by jackrabbits to agricultural fields in winter when compared to summer (Fig. 3).

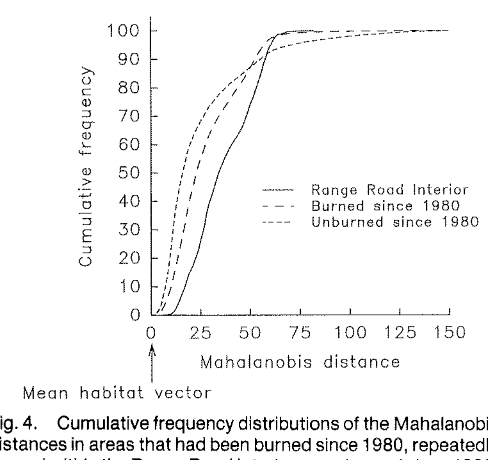

Fig. 4. Cumulative frequency distributions of the Mahalanobis distances in areas that had been burned since 1980, repeatedly burned within the Range Road Interior, or unburned since 1980.

Burned areas resulting from wildfires or ignited by military training had larger Mahalanobis distances (or less similarity to the mean habitat vector) in comparison to areas that had not burned after 1980 (Fig. 4). Areas that had burned 1–4 times since 1980 were intermediate in distribution to areas that had not burned since 1980 and the Range Road Interior, which was repeatedly burned (Fig. 4). Areas that had been burned were associated with loss of shrubs and, consequently, low similarity to the habitats used by jackrabbits on our surveys (Fig. 5).

DISCUSSION

We mapped the Mahalanobis distance as an index of habitat for black-tailed jackrabbits in a 440,000-ha region of southwestern Idaho. We emphasize that the GIS map did not predict an actual probability of occurrence or presence of jackrabbits. The map simply represented the similarity of GIS variables at the cell's location relative to mean vector of the multivariate set of habitat characteristics associated with previous jackrabbit sightings. Nonetheless, we demonstrated from the verification surveys that this

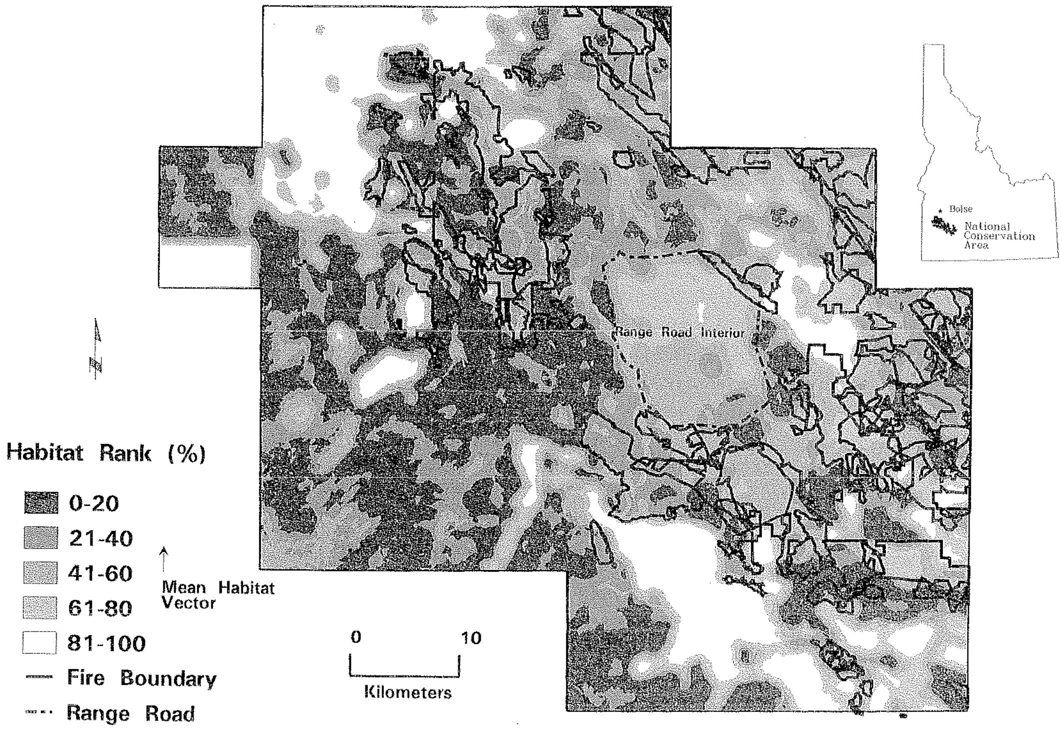

Fig. 5. Boundaries of wildfires and the Range Road Interior relative to habitat cells ranked by the Mahalanobis distance to the mean habitat vector of habitat associations for black-tailed jackrabbits in southwestern Idaho. Ranks were scaled into 20% quantiles of the distribution for the entire map.

technique identified areas most likely to contain jackrabbits.

The general distribution of habitat ranks did not change relative to population phase and suggests that jackrabbits continued to use similar habitats. We expected that our sightings during the high phase would be in a broader range of habitats because of overflow from optimal habitats, as described for snowshoe hares (*Lepus americanus*), another cyclic hare (Keith 1966, Wolff 1980). However, the difference in densities between population phase ($\bar{x}$ = 0.22 jackrabbits/ha high vs. 0.065 jackrabbits/ha low yr(s) of the population) without changes in distribution of habitats suggests that habitats were vacant during low population numbers, again similar to patterns of habitat occupancy during cyclic phases in snowshoe hare populations (Wolff 1981).

The spatial distribution of habitats changed between summer and winter seasons. Areas with high similarity (low Mahalanobis distances) to the mean habitat vector remained in the top rankings and were not spatially separate regardless of season of year or population phase (Fig. 2, also compare Fig. 3 and 5). Instead, intermediate or lower ranked habitat cells, especially areas containing agricultural fields, were associated with changes in the habitat rank.

MANAGEMENT IMPLICATIONS

We used GIS maps of a habitat index for black-tailed jackrabbits to demonstrate the relation of large-scale fires to spatial distribution of habitats likely to be used by jackrabbits. Large fires, either wildfires or unextinguished burns caused by military training, primarily altered habitats through loss of the shrublands associated with presence of jackrabbits. More than one-half of the shrublands in our study area has burned since 1980 and suggests that a substantial loss of habitats could seriously influence regional abundance of jackrabbits for dependent predators.

The loss of jackrabbit habitat due to fire has important long-term implications because of the low probability for restoring shrublands in arid and semiarid rangelands (Allen 1995). In addition to difficulties caused by low precipitation, shrublands converted to grasslands dominated by exotic annuals have a synergistic relation with fire that increases future intensity and frequency of disturbance. Therefore, the likelihood of natural regeneration of shrublands and restoration of habitats used by jackrabbits is decreased further (Whisenant 1990, D'Antonio and Vitousek 1992).

We demonstrated a technique for developing distribution maps of any species that can be related to a set of spatial habitat variables. In standard GIS overlay or GAP-analysis approaches (Scott et al. 1993), distribution maps are derived from generalized descriptions of animal habitats. In our method, GIS signatures of habitats were obtained directly from known animal locations. Because of the relative specificity of the habitat descriptions, this method could be used to monitor habitat change over time (e.g., comparisons before and after extensive wildfires), compare habitats among areas, or examine the effect of scale by developing GIS signatures for varying scales surrounding the locations.

Maps of wildlife and habitats generated by GIS should increase our understanding of spatial processes and contribute to land use planning by representing habitats from a species perspective. We used an index based on the Mahalanobis distance statistic, but recognize other mathematical models also could be used to derive similarity measures to a set of habitat variables for subsequent mapping by a GIS (Johansson et al. 1994, Andries et al. 1994, Mladenoff et al. 1995).

Our verification of the GIS map of jackrabbit habitats from sightings in 1993–95 indicated that our method could identify the spatial distribution of jackrabbit habitats at a fine scale over a relatively large area. Although the method is a relatively standard GIS manipulation, we caution that the quality of output is directly related to the selection of the variables used in creating the maps. We also recommend that maps should be associated with measures of accuracy by independent verification.

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